AQUEOUS ALTERATION OF ENSTATITE CHONDRITES. M.E. Zolensky[1], K. Ziegler[2], M.K. Weisberg[3,4], M. Gounelle[5], E.L. Berger[6], L. Le[6], A. Ivanov[7], [1]ARES, NASA Johnson Space Center, Houston, TX 77058 (michael.e.zolensky@nasa.gov), [2]Institute of Meteoritics, Univ. New Mexico, Albuquerque, NM 87131, [3]Kingsborough College, City University New York, Brooklyn, NY 11235, [4]Dept. Earth Planet. Sci., American Museum Natural History, NY, NY 10024, [5]Muséum National d'Histoire Naturelle, Paris, France, [6]Jacobs JETS, Houston, TX 77058, [7]Vernadsky Institute, Moscow, Russia.

Introduction: The Kaidun meteorite is different from all other meteorites [1], consisting largely of a mixture of "incompatible" types of meteoritic material – carbonaceous and enstatite chondrites, i.e. corresponding to the most oxidized and the most reduced samples of meteorite materials, including CI1, CM1-2, CV3, EH3-5, and EL3. In addition to these, minor amounts of ordinary and R chondrites are present. In addition, approximately half of the Kaidun lithologies are new materials not known as separate meteorites. Among these are aqueously altered enstatite chondrites [1], which are of considerable interest because they testify that not all reduced asteroids escaped late-stage oxidation, and hydrolysis, and also because hydrated enstatite chondrites are potential (though disputed) terrestrial planet building blocks [2-4]. Thus we are reexamining Kaidun enstatite chondrite lithologies.

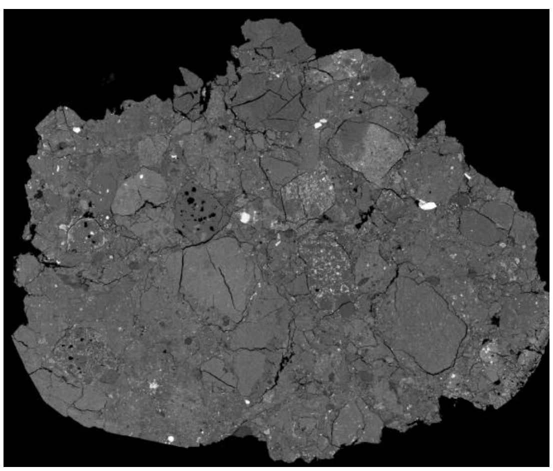

Figure 1. BSE image of Kaidun section D3. 5 cm across.

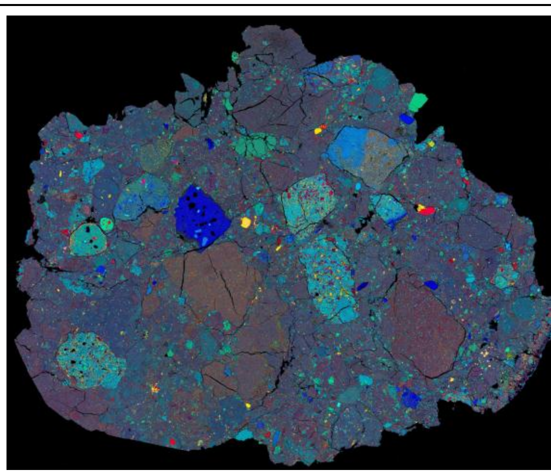

Figure 2. X-ray element map of Kaidun D3: Red=Fe, Green=Mg, Blue=Si, Cyan=Ca, Magenta=Ni, Yellow=S

E chondrite matrix: A hindrance to study of the aqueously altered enstatite chondrite lithologies has been the lack of detailed characterization of fine-grained matrix of EL3 and EH3 meteorites, a shortcoming now being addressed by Weisberg and coworkers [5]. As described by them fine-grained matrix in the E3 chondrites is a distinct reduced mineral assemblage mainly of silica (both crystalline and non-crystalline) and enstatite. Rounded, glassy silica grains contain tiny sulfide, plagioclase, schreibersite, and enstatite crystals. EL3 matrix is dominated by enstatite and albitic plagioclase; silica abundance is lower and albitic plagioclase higher than in EH3 matrix. Both EH3 and EL3 matrix contains silica grains, unusual sulfides (Cr-rich troilite, heideite, etc), and Fe-Ni phosphides not reported in other chondrite matrix.

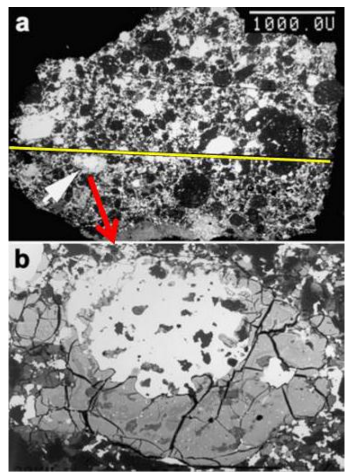

Figure 3. BSE images of EH3 lithology in Kaidun, (a) below the yellow line aqueous alteration is extensive, above the line it is absent, (b) closeup of metal (white) altering to serpentine (grey).

Hydrolysis has rendered most of these materials almost unrecognizable, since few of the original minerals have survived alteration. However, in most lithologies a few, rare, remnant grains can be linked to enstatite chondrites, as described below. Oxygen isotope analyses of a few representative lithologies are consistent with an origin as EL or EH material [6].

Alteration mineralogy: Figures 1 and 2 show views of a large Kaidun section, and illustrate that grain boundaries are abrupt. In fact thoroughly-altered enstatite chondrite clasts are adjacent to complexly unaltered enstatite chondrite material. Even within single clasts, the alteration front can be abrupt (Fig. 3). Carbide-containing metal is initially replaced by a

poorly crystalline Si-Fe phase, which in turn is replaced by serpentine (Figs 3-5). In the end the only indication of the original presence of metal is the residual carbides. In other enstatite chondrite lithogies (of uncertain type) original silicates and metal have been thoroughly replaced by an assemblage of authigenic plagioclase laths, calcite boxwork, and occasional residual grains of silica, Cr-rich troilite, ilmenite, and rare sulfides including heideite (Fig. 6). Fe and S have been largely leached from the rock (Fig. 4). Again the accessory phases are the first clue to the original character of the rock, which can be verified by O isotopes. It is fortunate that Kaidun displays every step of the alteration process.

Conclusions: Carbonaceous chondrite and enstatite chondrite rocks have been combined in nature, necessitating impacts between C-class and E- or M-class asteroids. Evidence for this process is also present in Sutter's Mill [7]. We do not know how frequently this occurred, but there were probably "wet" E- or M-class objects at the time the terrestrial planets formed.

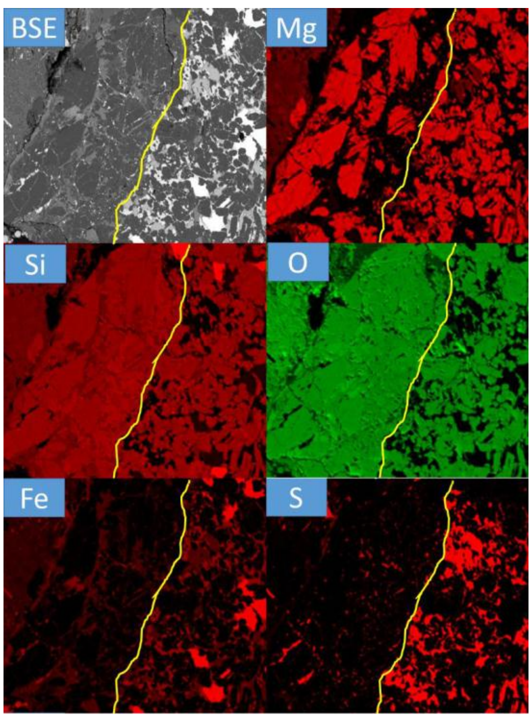

Figure 4. BSE and X-ray maps of boundary between unaltered (left of yellow line) and altered EH3 lithology in Kaidun. View is 140 µm across.

References: [1] Zolensky and Ivanov (2004) *Chemie der Erde* **63**, 185-246; [2] Wänke H. 1981. Constitution of the terrestrial planets. *Philosophical Transactions of the Royal Society of London A* **303**, 287–302; [3] Burbine and O'Brien (2004) *MAPS* **39**, 667–681; [4] Fitoussi and Bourdon (2012) *Science* **335**, 1477-1480; [5] Weisberg et al. (2014) *45th Lunar and Planetary Science Conference*; [6] Ziegler et al. (2012) *43rd Lunar and Planetary Science Conference;* [7] Zolensky et al., submitted to *MAPS.*

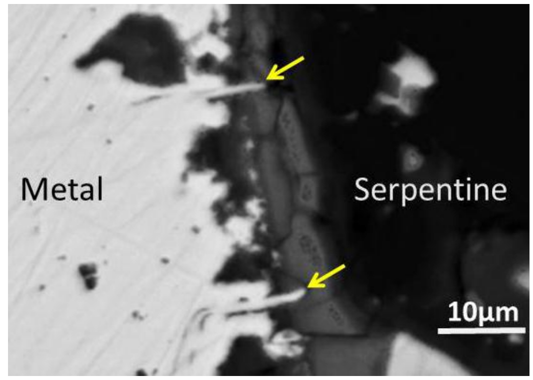

Figure 5. BSE image of altering metal grain in EH3, showing poorly crystalline Fe-Si materials (grey) beyween metal and serpentine. Cohenite laths are arrowed

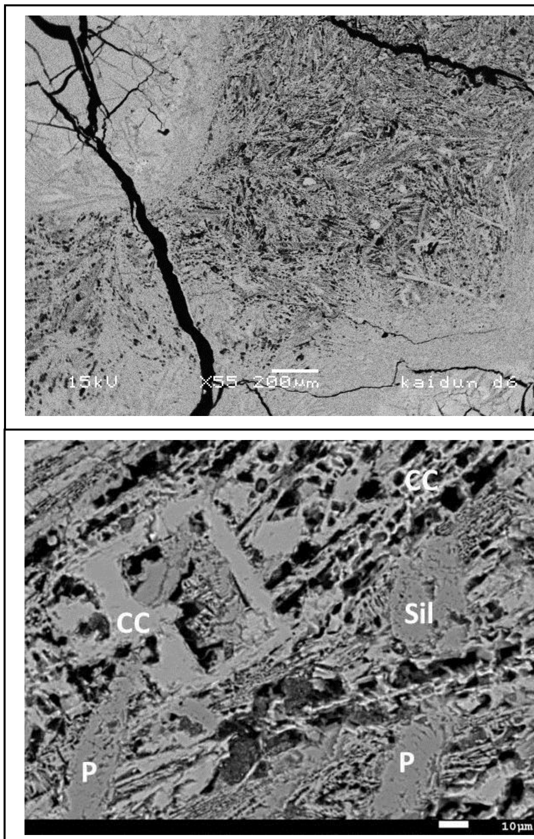

Figure 6. BSE images of porous assemblage of authigenic plagioclase (P), calcite (CC) and silica (Sil) replacing the original E3 chondrite. (top) Low mag, (bottom) higher mag.